BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: STAC Action Item: Discussion of Sun-Synchronous Orbits and their Applications - Case 600-4

DATE: September 18, 1967

FROM: F. G. Allen
R. Y. Pei

ABSTRACT

The oblateness of the earth (its equatorial bulge) causes a perturbation of the orbits of earth satellites which, under certain conditions, causes the "plane" of the orbit to precess about the axis of rotation just once each year, thus keeping "in step" with the sun. The properties of the family of such orbits are presented. Two areas where these are of special interest are solar astronomy and certain earth observations.

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MEMORANDUM FOR FILE

A sun-synchronous orbit is an earth orbit whose plane rotates about the earth's axis just one revolution per year and thus remains "in step" with the earth's rotation about the sun. Such orbits are possible because of the perturbations due to the earth's oblateness. The added attraction of the earth's equatorial bulge introduces a force normal to and toward the plane of the equator which, under the right conditions, causes the correct precession. An example is given in Figure 1, showing the position of the orbital plane relative to the earth's axis and the sun throughout the year. Note that in general, since the orbital plane precesses about the earth's axis which is inclined 23-1/2° to the ecliptic, it does not maintain a fixed angle relative to the earth-sun line during the year.

When the expression for the precession rate due to the earth's oblateness is set equal to one revolution per year and solved to first order terms for circular orbits, not one but a family of orbits results, having different pairs of altitude and inclination values. This family is shown in Figure 2, where the locus of all sun-synchronous orbits is shown by the curve. It is seen in Figure 2 that the altitude varies smoothly from about 200 NM in near-polar orbit to about 3200 NM near the equator. This change is as expected. The effect of the equatorial bulge is weakest near the poles, strongest near the equatorial plane. Hence, the altitudes of near-polar orbits must be less (closer to the earth), than those of near-equatorial ones if the same perturbation is to result. Note that the manned program could use near polar sun synchronous orbits for altitudes up to about 300 NM before radiation problem gets severe.

It is important to note that in order for the precession to be of the right duration to track the sun, all the orbits shown in Figure 2 are retrograde, that is, opposite to the direction of the earth's rotation. Hence, the inclination angles, i, are all <u>more</u> than 90°, and are the supplements of the usual angles given (84° in Figure 2 = 180°-84 = 96° in the usual notation).

For circular orbits, the nodes of the orbital plane regress as described, and for elliptical orbits, there is in addition, a rotation of the apses in the orbital plane.

Sun-synchronous orbits have special interest both for solar observation and for certain types of earth observation.

For solar astronomy it is possible, by choosing that portion of the family lying above 65° inclination, to avoid occultation of the sun by the earth completely. Hence, at orbital altitudes from 200 to 1700 NM and corresponding inclinations (84 to 65°), a telescope observing the sun will never be shadowed by the earth. This is a significant advantage because

a) it provides continuous observations of on-going solar events without being interrupted once each revolution and then having to re-acquire the feature later;

b) it avoids severe thermal cycling and permits equipment to come to a steady state.

Note, however, that many other high altitude high-inclination orbits, not exactly sun-synchronous, can satisfy both these conditions for large fractions of a year.

The advantages of sun-synchronous orbits for earth observation are more limited. It is possible to view all portions of the earth (except near the poles) at nearly the same solar time all the year 'round by choosing the sun-synchronous plane to be nearly polar. For example, if the plane is chosen to include the earth-sun line, the ground track will always be at nearly midday and midnight. In this case, the sun looks at the plane of the orbiting satellite edge-on, and the plane splits the earth from approximately North to South Poles. If the plane is nearly polar but makes some angle with the earth-sun line other than zero, the solar time on the ground track will still be nearly constant but something other than midday and midnight.

It is <u>not</u> true that sun-synchronous orbits permit viewing most of the earth at a constant sun-angle the year 'round, since variation of this angle with latitude and with the season of the year remain important.

F. G. Allen

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R. Y. Pei

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Attachment
Figures 1-2

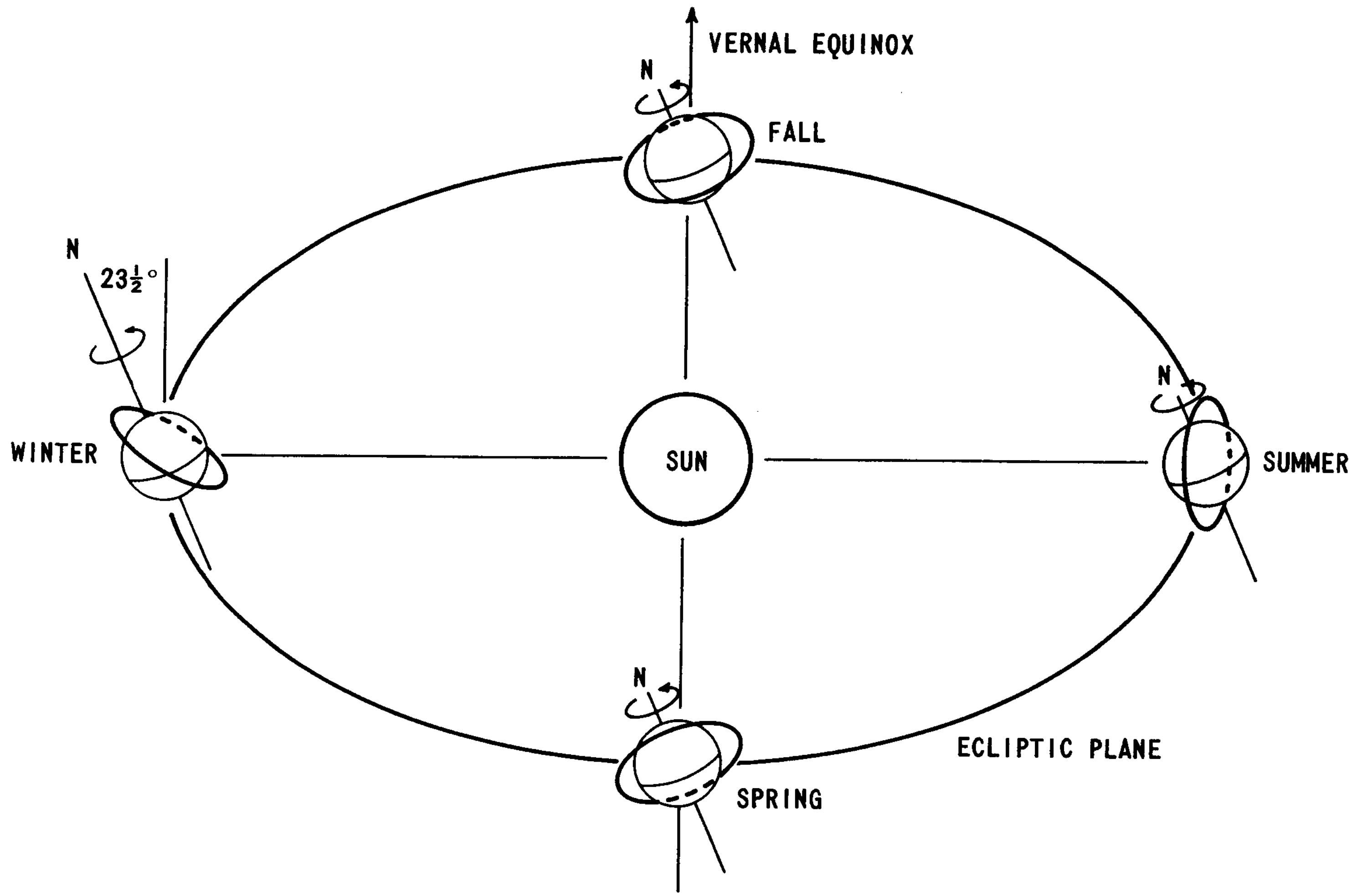

FIGURE 1 - ORBIT IN EARTH-SUN SYSTEM

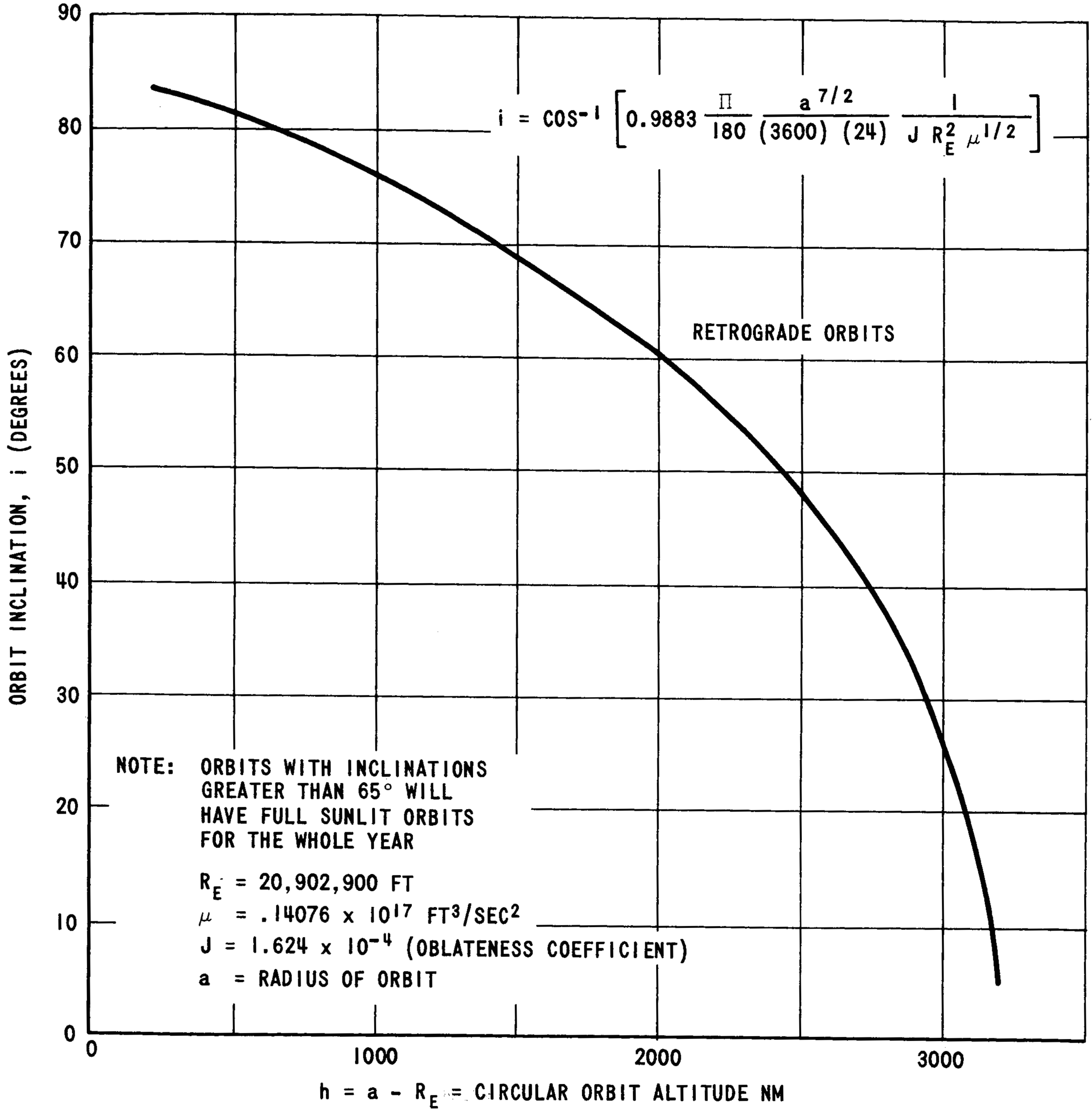

FIGURE 2 - CIRCULAR ORBIT ALTITUDE vs. INCLINATION
FOR SUN SYNCHRONOUS ORBIT

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